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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Deployment of Reentry Ships During
Mission AS-202 to Obtain Pertinent
Data on RF Communication Blackout

TM- 65-2021-8

FILING CASE NO(S)- 320

DATE- December 17, 1965

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FILING SUBJECT(S)- Reentry Communications Blackout
(ASSIGNED BY AUTHOR(S)) AS 202 Reentry Ship

ABSTRACT

Possible ship locations for communication and tracking coverage during the reentry phase of the unmanned Apollo-Saturn Mission 202 have been examined. Certain locations of the reentry ships would provide pertinent flight test data on the radio frequency blackout for the full size Apollo CM. Such data would be of great value in improving and verifying the existing theory for blackout prediction, and in planning the reentry ship deployment for subsequent Apollo missions.

Optimum reentry ship locations were selected to obtain the maximum useful data for both mission operational planning and scientific purposes. It was concluded that the deployment of even a single ship could provide valuable information for the Apollo program. The deployment of four ships would provide coverage for the entire reentry period.

The final trajectory for Mission 202 may be modified from the trajectory discussed in this memorandum. However, it would not change the overall conclusions of this study although some change in the ship locations would be required.

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PERTINENT DATA ON RF COMMUNICATION BLACKOUT
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TECHNICAL MEMORANDUM

I. Introduction

Continuous communication and tracking between an Apollo spacecraft reentering the Earth's atmosphere and the MSFN ground stations is not possible because of attenuation by the plasma surrounding the reentering spacecraft. Depending on the particular reentry trajectory chosen for the mission, it is possible to establish normal communication and tracking for portions of the reentry phase. For the manned missions, one or two reentry ships are planned to be used to, (1) establish normal communication and transponder tracking of the spacecraft when it is not in the RF blackout region, and (2) skin track the plasma sheath of the spacecraft while it is in RF blackout region.

In order to position reentry ships for maximum utility, it is necessary to anticipate the RF plasma blackout boundaries for the particular mission involved. At the present time, despite the number of people working on reentry phenomena, the knowledge for making reasonably accurate RF blackout predictions is limited; consequently, the best deployment of the reentry ships cannot be determined at this time.

Apollo-Saturn Mission 202 is planned as a long lob unmanned flight of the CSM with a reentry velocity of approximately 29,000 ft/sec. Its primary objective is testing the heat shield of the CSM. This particular mission provides an excellent opportunity for defining the extent of the communications blackout and for establishing the blackout boundaries for the Apollo spacecraft if appropriate communication and tracking coverage is provided. The information obtained from this mission could provide, (1) flight test data on a full size CM, and (2) improved knowledge of the blackout phenomenon for the planning of subsequent missions.

Section II of this memorandum describes the reentry profile for Apollo-Saturn Mission 202 as it is being planned at present. The expected RF blackout regions for the Mission AS-202 reentry trajectory, based on available predictions, are discussed in Section III. The investigation of ship locations for providing the desired communication and tracking coverage is presented in Section IV. A brief discussion of the desirable implementation on the ships is included in Section V, and the conclusions and recommendations are presented in Section VI.

II. Apollo-Saturn Mission 202 Reentry Profile

The overall ground track and reentry profile of Apollo-Saturn Mission 202 are extracted from a joint reference trajectory document⁽¹⁾, and are reproduced here as Figures 1 and 2*. From Figure 1 it is seen that all of the reentry ground track, except the very beginning of the reentry phase, will not be covered by any communication and tracking station. It is also seen that nearly all of the reentry ground track will be over the Pacific Ocean. Therefore, any possible communication and tracking coverage would have to be provided by ships. More recent information indicates that there may be a change in the final flight plan to move the reentry point** further down range with a higher reentry velocity for the spacecraft. These changes would affect the exact ship locations for communication and tracking coverage, however, it would not alter the overall discussion and content of this analysis significantly.

III. RF Blackout from Reentry Plasma

The Apollo-type reentry at superorbital velocity presents a unique problem in the prediction of RF plasma blackout phenomenon. The knowledge of flow field analysis, chemical kinetics, and the interaction between electromagnetic waves and the plasma is incomplete at the present time. The existing RF blackout predictions

(1) "Apollo Trajectory Document No. 65-FMP-1, Apollo Mission 202 Joint Reference Trajectory," issued by MSFC and MSC, April 12, 1965. (Confidential).

* The figures reproduced here are unclassified portions of the document.

** The reentry point is defined as the point where a reentering spacecraft arrives at the altitude of 400,000 ft.

made for an Apollo-type reentry have to rely on, to various degrees, unproven techniques and assumptions. Some of these predictions, applying to the Mission 202 reentry profile, are summarized in Figure 3. These predictions were made by North American Aviation Inc. (NAA), Langley Research Center (LRC), and Goddard Space Flight Center (GSFC)^{(2),(3),(4)}. Their end results, as seen in Figure 3 differ and do not provide the accuracy needed for mission operational planning purposes.

Studies are now being made at Cornell Aeronautical Laboratory (CAL), under NASA contract, to better define the plasma parameters associated with the Apollo CM shape and reentry conditions. However, the accuracy and validity of the theoretical models used for the study need to be verified by full scale flight results, such as Mission AS-202 could provide.

IV. Determination of Reentry Ship Locations

The locations for the reentry ships are determined from the considerations of visibility, anticipated communications blackout, and the critical portions of the Mission AS-202 reentry profile.

A. Communication Coverage

Using a computer program developed at Bellcomm, reentry trajectory coverage data was obtained for a total of seventeen different ship locations. Input data of longitude, latitude, altitude of the CM, and the time from the start of reentry were taken from Table C-6 of Reference 1. These coverage results are shown in Table I along with the coordinates of the ship locations. The locations were selected along the sub-vehicle track which means that the vehicle would pass directly over a ship at these locations. Actually the antenna mount on the ship would not permit the antenna to be slewed uninterruptedly overhead but

(2) "Final Report on Apollo Plasma Reentry Studies," NAA/S&ID Report SID 63-746, July 5, 1963.

(3) R. Lehnert and B. Rosenbaum, "Plasma Effects on Apollo Reentry Communication," NASA Tech. Note (NASA-TN-D-2732), March, 1965.

(4) P. W. Huber and T. Sims, "Research Approach to the Problems of Reentry Communications Blackout," presented at the Third Symposium on the Plasma Sheath, September 21-23, 1965.

there would be a keyhole of several degrees. This discontinuity is not shown in the results presented. This keyhole would be avoided by locating the ship a short distance off the track and continuous tracking would be obtained.

From Table I it is seen that the minimum coverage time (allowing 5° elevation angle from the ship) of the selected ship locations is 153 seconds (at Location D) and the maximum coverage time is 195 seconds (at Location Q). The average coverage time for all seventeen locations is 169 seconds.

B. Criteria for the Selection of Ship Locations

The preferred choice of ship locations is determined by, (1) the number of ships available and (2) the blackout regions of maximum interest. Preferred locations were selected for one, two, three, and four ships. Two factors are considered for the second criterion. They are, (1) the scientific value of the RF blackout data from the different blackout regions, and (2) establishing RF blackout boundaries to permit optimum deployment of reentry ships in future missions.

From Figure 3, it is seen that extensive blackout is expected over most of the reentry period for VHF frequency. For S-band and C-band frequencies, two blackout periods are expected which occur at the beginning and the end of the reentry period.

The blackout period can be divided into four regions (Figure 3), Regions 1 and 3 represent the area for the spacecraft entering RF blackout, and Regions 2 and 4 represent the area for the spacecraft emerging from the RF blackout. The relative importance of obtaining data on these RF blackout regions is discussed next.

1) Scientific Data Evaluation - Full scale flight test data are needed to verify and improve the current studies for Apollo-type reentry blackout phenomenon, especially for the Cornell Aeronautical Laboratory study which is the only existing detailed and comprehensive effort aimed specifically at the Apollo blackout problem. The greatest uncertainty with the present theory is in the area of chemical kinetics when a large energy exchange occurs between the reentering vehicle and the surrounding atmosphere. The higher the energy exchange rate, the less knowledge exists of the processes. Figure 4 is the total heat and heat rate profiles for Mission AS-202 during its reentry phase as extracted from Reference 1. From the heat rate curve, it is seen that the maximum heat rate, which corresponds

to the greater energy exchange rate, occurs in Regions 1 and 2, and the smaller heat rate occurs in Regions 3 and 4. Therefore, the RF blackout data from the Regions 1 and 2 would be of more value.

Although the reentry velocity (29,000 ft/sec) of Mission AS-202 does not simulate exactly the Apollo lunar landing mission which will have a higher reentry velocity (36,000 ft/sec) and, therefore, a more severe RF blackout problem, the data collected from Mission AS-202 would permit the evaluation of the theoretical studies. Similarly, the communication frequency planned for lunar missions will only be at S-band during reentry, but the RF blackout data collected on several frequencies, (especially at C-band) will facilitate the theoretical evaluation.

2) Reentry Ship Deployment for Future Missions - From Figure 3, it is seen that the "skip" portion of the reentry profile of Mission AS-202, between Regions 2 and 3, is expected to be a clear region for the C-band and S-band frequencies. This would also be true for other Apollo missions provided the "skip" attains sufficiently high altitude. It is obvious that the desirable location of the reentry ship for subsequent Apollo missions would be under the "skip" region in order to establish normal communications and tracking with the CM. Therefore, it is important to know the RF blackout boundaries of Regions 2 and 3. The RF blackout boundaries for Regions 2 and 3 should theoretically occur at approximately the same altitude. This occurs because the velocity of the CM remains approximately the same during the "skip" portion of the trajectory. Consequently, the knowledge of the RF blackout boundary of either Region 2 or 3 would be adequate for both regions.

The Apollo CM is designed to be a maneuverable vehicle for its reentry flight in contrast with the ballistic flight trajectory of the Mercury spacecraft during its reentry. More tracking data would be needed for the Apollo-type reentry in order to predict the landing point of the CM with certainty. In general, the maneuverability of the CM becomes progressively less with time after the initiation of the reentry phase, and the uncertainty of the exact landing point is also reduced as tracking data is obtained along the flight path. Since tracking data would be available before the spacecraft entering RF blackout, tracking data from Region 1 is not critical for

landing point prediction. Region 4 occurs at an area where the spacecraft has lost almost all of its maneuverability and the landing point is determined quite well. Tracking data from Regions 2 and 3 would provide the more important inputs to the prediction of the landing point. Since the "skip" portion of the trajectory is nearly a ballistic path, tracking data for prediction from Region 2 would be preferred as it would be available at an earlier time.

C. Recommended Ship Locations

From the considerations outlined above, it is seen that the RF blackout regions of interest can be ranked in the order of Region 2, Region 1, Region 3, and Region 4. The data for Region 2 would be of maximum use. The corresponding ship locations for the Mission 202 reentry communications coverage would be as follows:

<u>No. of Ships</u>	<u>Ship Locations*</u>	<u>RF Blackout Regions Covered</u>
1	E	2
2	C, E	1, 2
3	C, E, O	1, 2, 3
4	C, E, J, P	1, 2, 3, 4

The coverage provided by these ships are shown in Figures 5 and 6.

It should be noted that, under present planning, a tracking ship, USNS General Vandenburg, will be located at approximately 7.4°S, 132°E for the purpose of tracking the separation of the CM from the SM which precedes the reentry phase. The visibility of the ship would allow it to track the CM descending to the altitude of approximately 325,000 ft. as shown in Figures 5 and 6. It is seen that if this ship were moved further down range, it would also be able to provide some coverage for Region 1.

* The ship locations refer to those indicated in Table I.

V. Ship Implementation and Data Requirements

For the purpose of determining the RF blackout boundaries during the Mission AS-202 reentry flight, the reentry ships should be equipped with a C-band tracking radar which is capable of both skin tracking and beacon tracking the Apollo CM. It should, preferably, also be equipped with an S-band receiving system capable of receiving the Apollo CM transponder for signal strength recording. The S-band antenna on the ship could be slaved to the C-band tracking radar. For the coverages of Regions 1 and 4, VHF receiving equipment should also be available to permit the recording of the VHF signal from the CM.

Past experience has indicated that considerable difficulty can be expected when a radar skin tracks the wake region of a space vehicle plasma. Therefore, it is recommended that the ships stationed at locations C, J, and O use the beacon tracking mode initially, and switch over to the skin tracking mode after the RF blackout begins. The ships located at locations E and P should use the skin track mode initially and switch over to the beacon tracking mode after the end of RF blackout. There would also be difficulty in acquiring the Apollo CM in the skin tracking mode unless an adequate acquisition aid were provided for the tracking radar. In order to evaluate the problem of acquiring the CM with the existing implementation on the tracking ships, additional studies are needed to determine the probable dispersion of the Mission 202 reentry trajectory.

For post mission analysis, the following data would be desirable for the reentry phase:

- (a) signal strength recordings for all frequencies,
- (b) radar cross section data of the CM during RF blackout,
- (c) the velocity history of the CM,
- (d) the ephemeris, and attitude history of the CM,
- (e) the radiation patterns of the CM antennas, and
- (f) the temperature and pressure data of the CM body.

VI. Conclusions and Recommendations

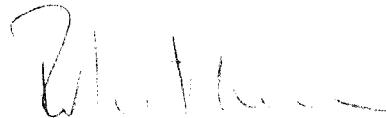
From the above considerations, it is concluded that:

1) Experimental flight data on RF blackout boundaries during the reentry phase of Apollo missions are needed to improve and verify the present RF blackout prediction theories, and for the operational planning of future missions.

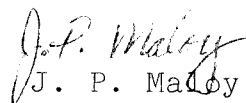
2) Apollo-Saturn Mission AS-202 provides an excellent and early opportunity for the determination of RF blackout boundaries for the full size Apollo CM.

3) Valuable data can be collected with the deployment of a single ship at the location of approximately 3.8°N, 149.2°E; the ship would provide data for approximately 170 seconds. Four ships would provide coverage of the complete reentry trajectory.

It is recommended that at least one ship be deployed in the reentry area for the Apollo Saturn Mission 202 to determine the RF blackout boundaries. It is further recommended that consideration be given to the possibility of moving the location of the tracking ship being used to monitor the CM-SM separation further down range in order to provide some RF blackout coverage.



R. K. Chen



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Attached
Figures 1-6
Table I

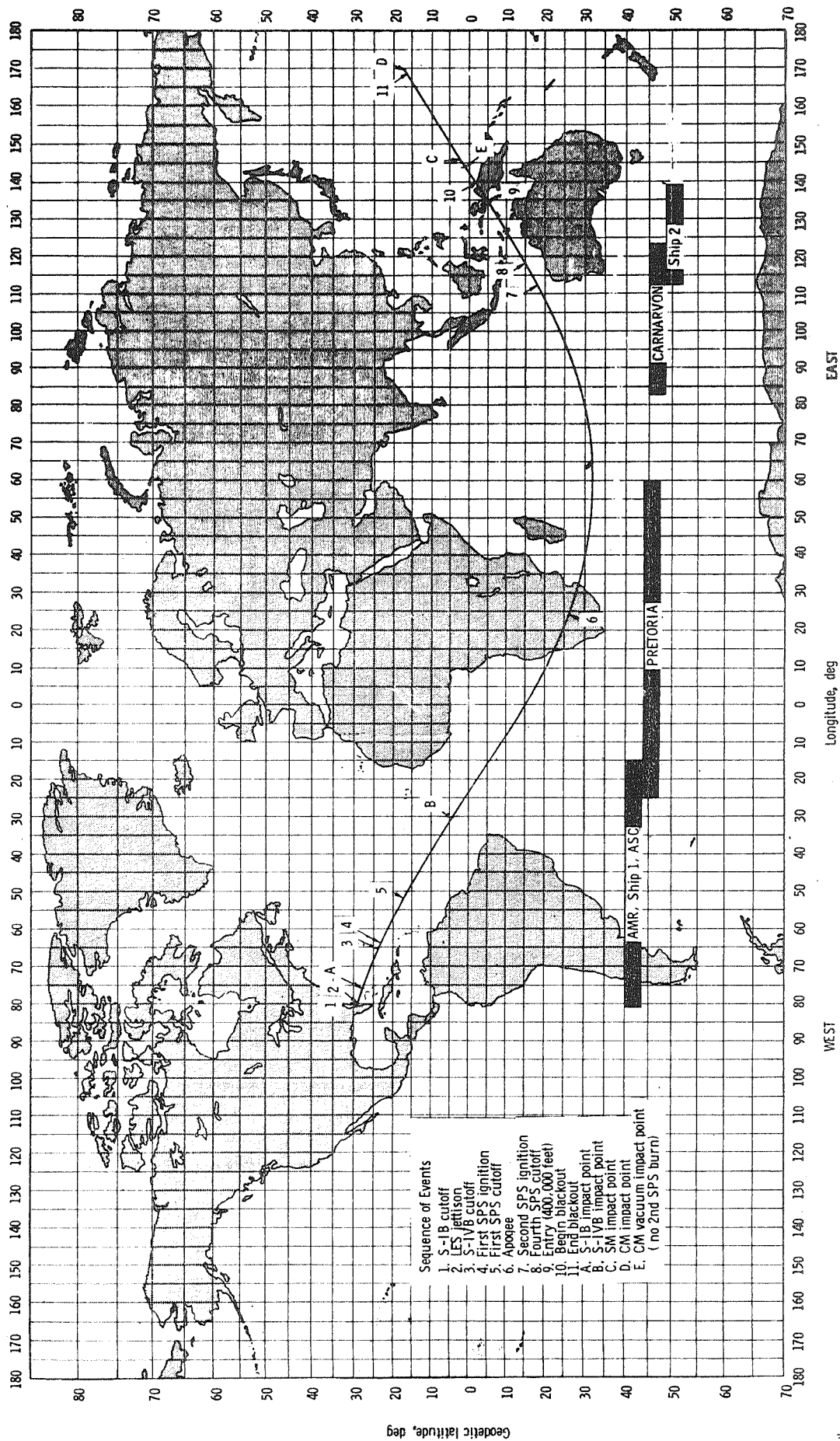


FIGURE 1 - SA-202 GROUND TRACK

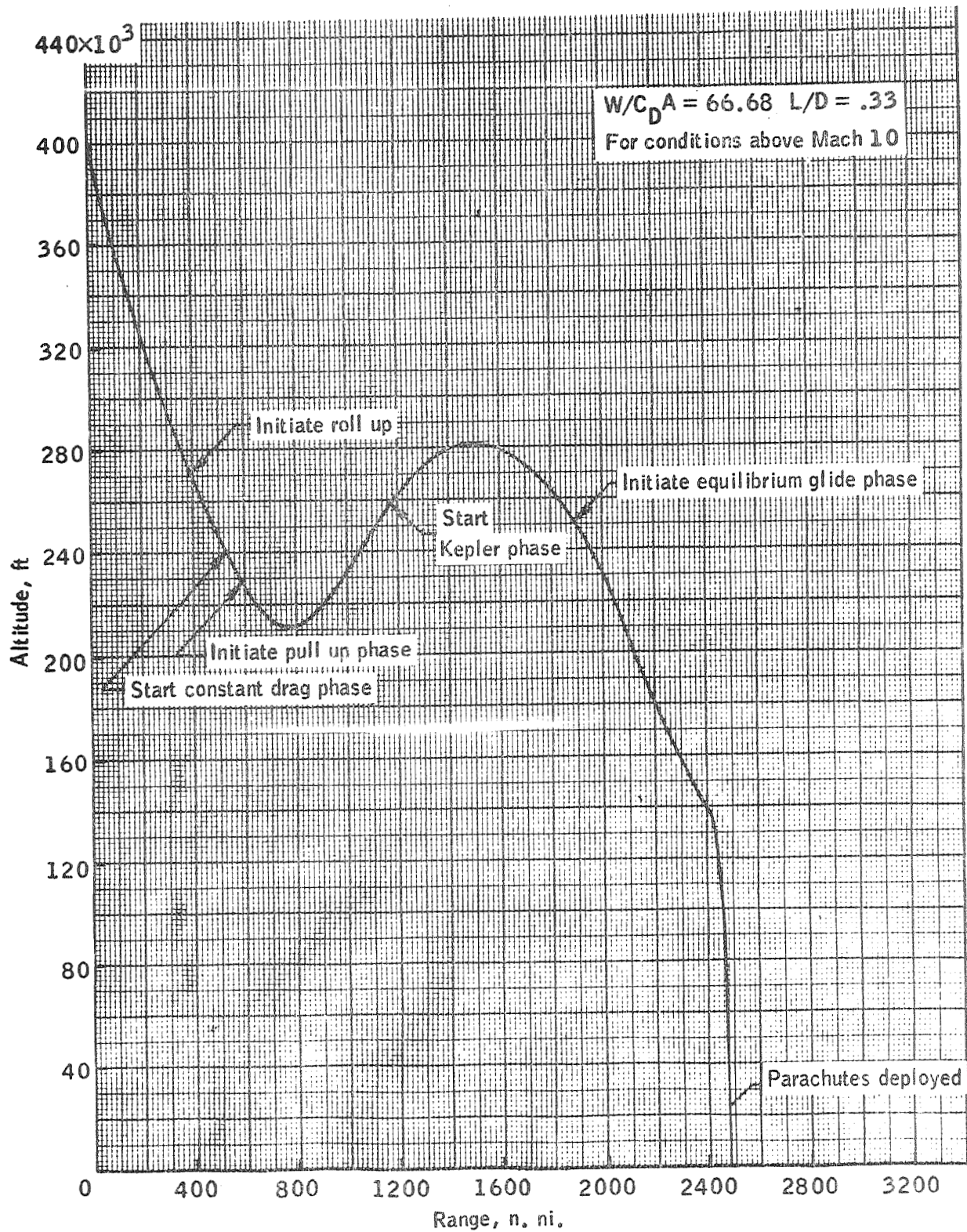


FIGURE 2 - ALTITUDE RANGE PROFILE DURING ENTRY

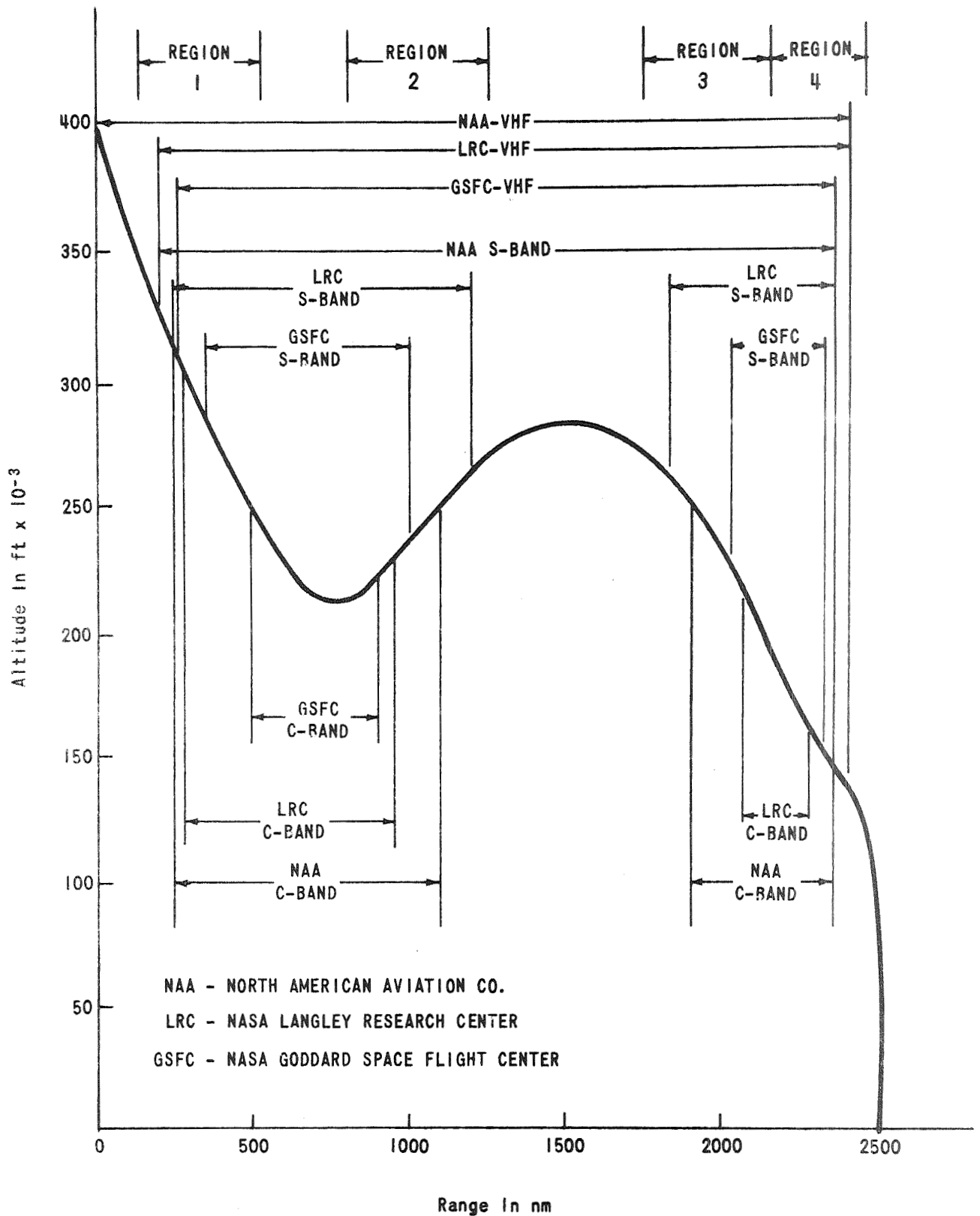


FIGURE 3 ESTIMATED REENTRY RF BLACKOUT FOR APOLLO SATURN MISSION 202 BASED ON AVAILABLE PREDICTIONS

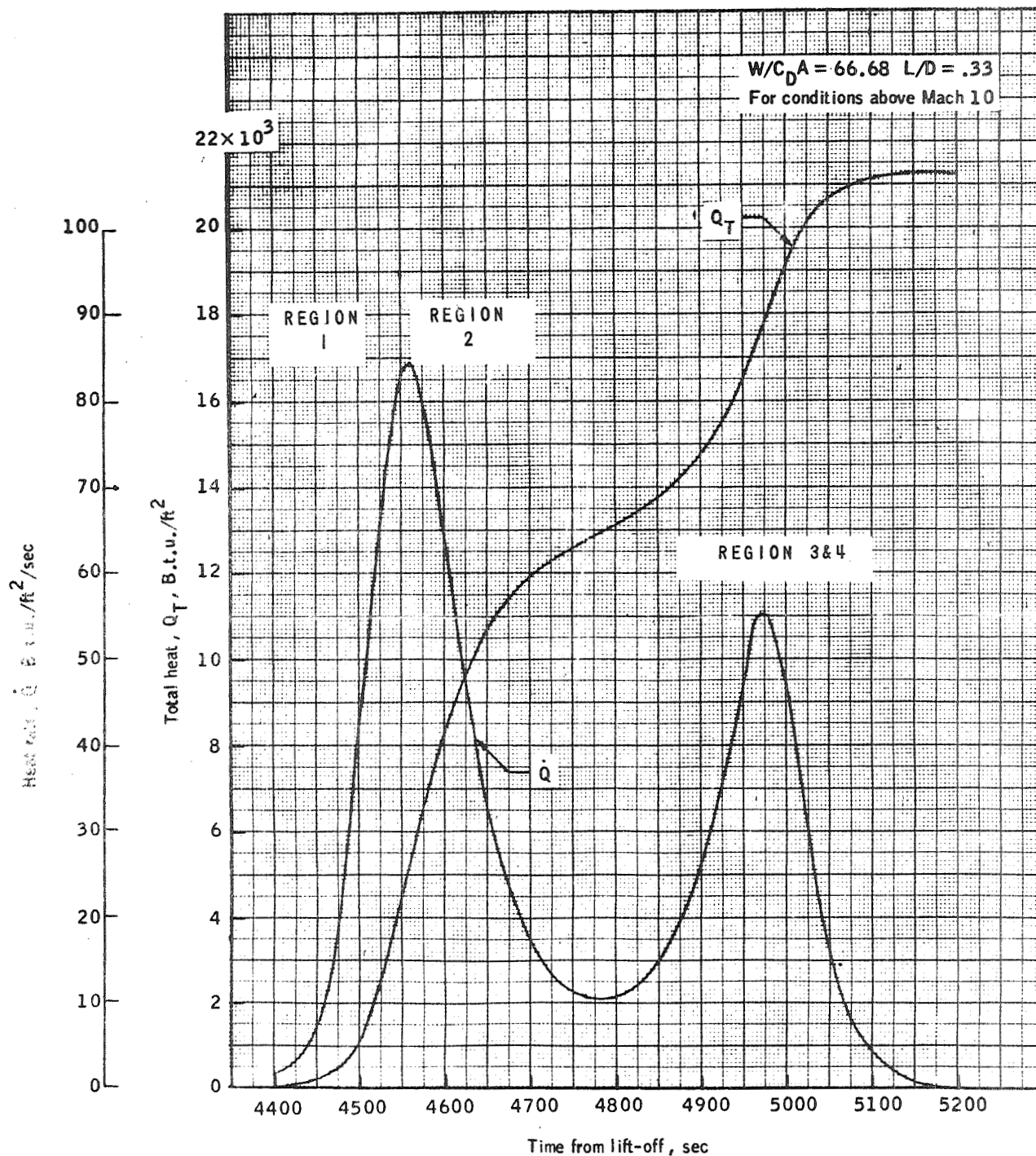


FIGURE 4 - TOTAL HEAT AND HEAT RATE VERSUS TIME FROM LIFT-OFF

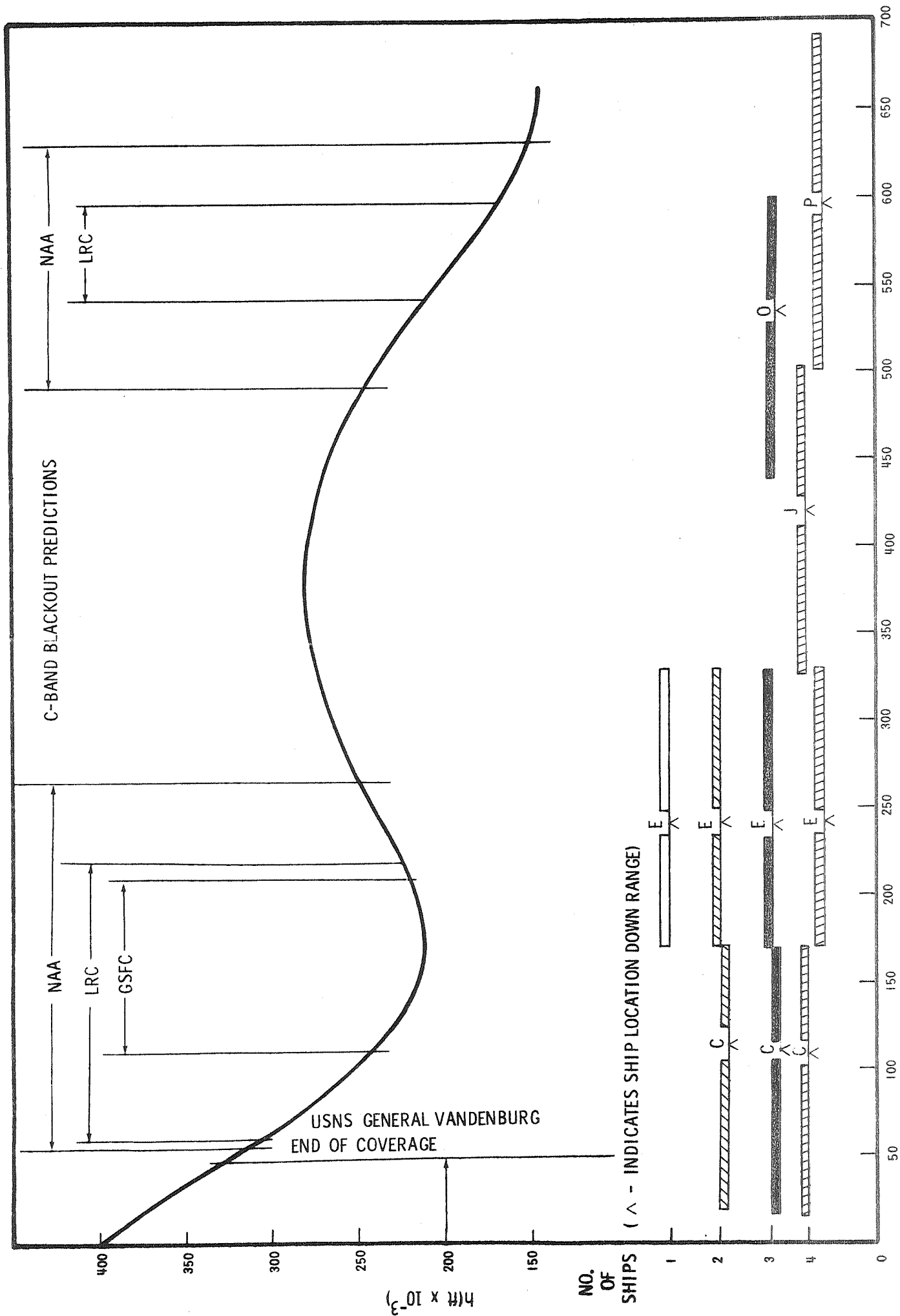


FIGURE 5 COMMUNICATION COVERAGE FOR APOLLO SATURN MISSION 202 PROVIDED BY
PROPOSED SHIP LOCATIONS DURING REENTRY RF BLACKOUT

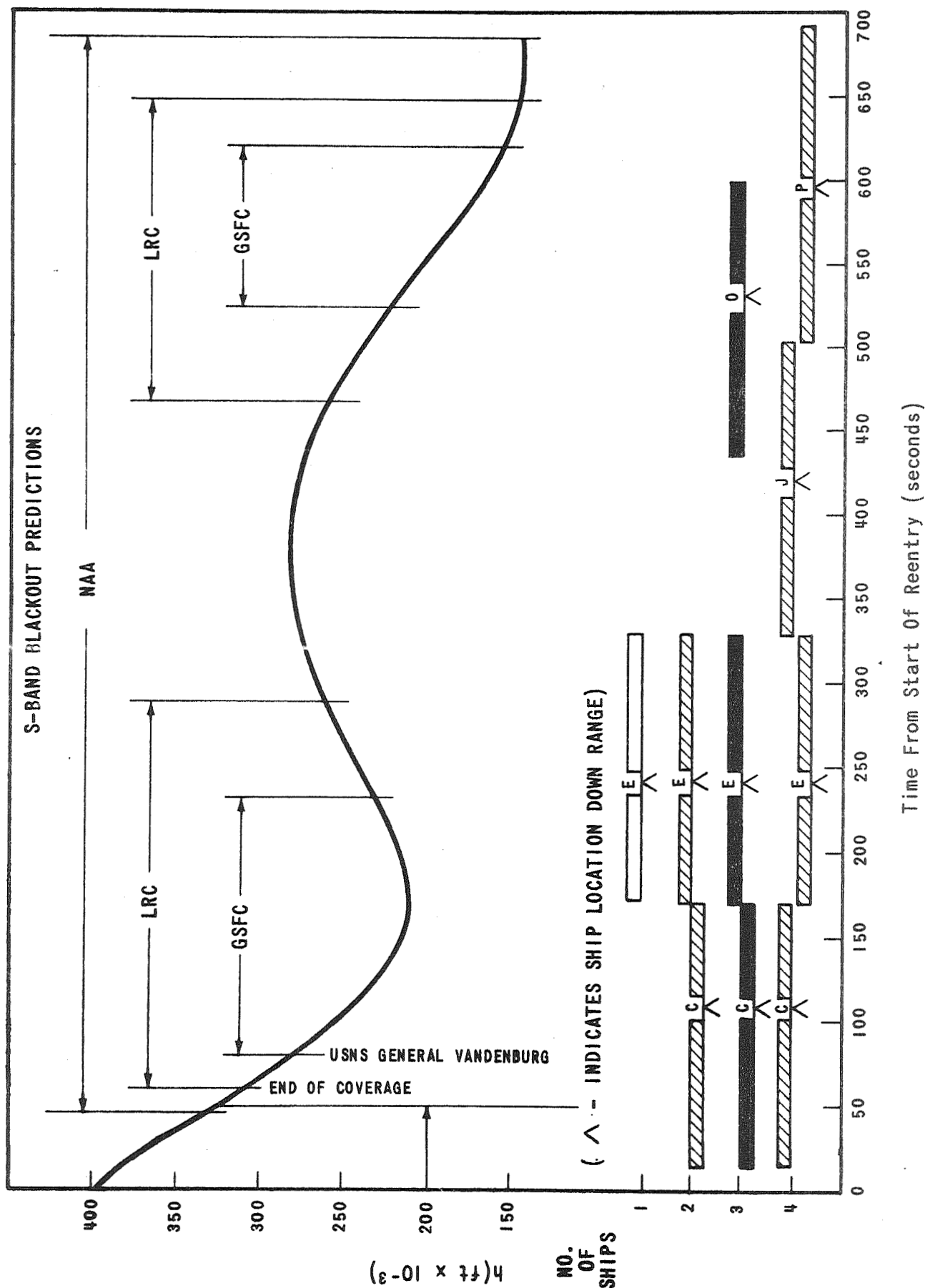


FIGURE 6 COMMUNICATION COVERAGE FOR APOLLO SATURN MISSION 202 PROVIDED BY PROPOSED SHIP LOCATIONS DURING REENTRY RF BLACKOUT

TABLE 1

MISSION AS - 202
SHIP LOCATIONS AND REENTRY COVERAGE PROVIDED

SHIP POSITION	LAT.	LONG.	TIME (SECS) FROM START OF REENTRY		
			PICK-UP	DROP-OUT	DIFF (APPROX)
A	1. 571S	140. 947E	0	158. 92	159
B	1. 329S	141. 321E	7. 35	164. 95	158
C	1. 087S	141. 694E	15. 90	171. 18	155
D	0. 845S	142. 066E	24. 37	177. 66	153
E	3. 794N	149. 220E	169. 47	330. 85	161
F	3. 996N	149. 529E	174. 97	337. 43	162
G	4. 197N	149. 837E	180. 37	343. 88	164
H	4. 397N	150. 143E	185. 69	350. 24	165
I	8. 359N	156. 306E	291. 08	468. 29	177
J	9. 626N	158. 331E	327. 55	503. 63	176
K	10. 002N	158. 941E	338. 76	514. 00	175
L	10. 627N	159. 959E	357. 88	531. 03	173
M	10. 875N	160. 367E	365. 69	537. 73	172
N	11. 492N	161. 387E	385. 46	554. 30	169
O	12. 943N	163. 821E	434. 68	597. 90	162
P	14. 803N	166. 869E	502. 49	693. 39	191
Q	14. 955N	167. 100E	508. 10	703. 47	195